APPLICATION NOTE 21

This application note describes a three IC, 4-20mA process current, digital-to-analog converter that can be constructed at low cost. It operates from a $-5V \pm 1V$ negative power supply and a $+23V \pm 7V$ positive power supply, has 24V output voltage compliance, and occupies less than 4 square inches of printed circuit board space. Other significant features include TTL logic input compatibility, 8-bit binary coding, 0° to $+70°C$ operation, and $5\mu s$ full scale settling time into a 500Ω load.

THEORY OF OPERATION

A fixed current of 0.5mA is added to a DAC's output current varying between 0 and 2.0mA and the resulting total current is multiplied by a factor of 8 to produce an output current of 4.0 to 20mA.

In the schematic, first note the REF-01CJ, a $+10V$ adjustable reference. Its output goes to the noninverting input of one half of A3, a dual precision op amp. The inverting input is within a feedback loop forcing $+10V$ to appear at the top of R4, a $20k\Omega$ resistor; a 0.5mA current will flow in R4

through Q1, a high h_{FE} transistor. The same $+10V$ is applied to R3, the reference input resistor of a multiplying IC D/A converter, the DAC-08. Full scale output current of the DAC will be the difference in voltage between the $+10V$ reference and Pin 14 of the DAC divided by R3; Pin 15 will be at the same voltage as Pin 14 because it is a high impedance point, the noninverting input of an op amp internal to the DAC. After calibration a current of 0 to 2mA (depending on the digital input code) will flow into the DAC's output, Pin 4.

Both the DAC's output current and the fixed 0.5mA flow in R5, a 800Ω precision resistor. The voltage developed by that current is applied to the noninverting input of the other half of A3 and will also appear across R6, a 100Ω precision resistor. Thus, eight times the 0.5 to 2.5mA current in R5 flows in R6, or 4 to 20mA. Almost all of this current appears at the output because the 2N6053 is a high h_{FE} device, a power darlington transistor.

Some other components need explanation. C1 provides frequency compensation of the DAC's reference amplifier; C2

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prevents high freque
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CALIBRATION PR

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R1 until the output cu
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OUTPUT VOLTAC

Output voltage com
$= +16V$, the output
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Maximum $= 1.2k\Omega$

SCALE MODIFIC

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4-20mA requiremen
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and change R6 to

CONCLUSION

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SCHEMATIC DIAGRAM

OUTPUT VOLTAGE COMPLIANCE (V_{OC})	
V_{CC}	V_{OC}
16V	10V
23V	17V
30V	24V

*SETTLING TIME $\cong 5\mu SEC$ WITH $R_L = 500\Omega$
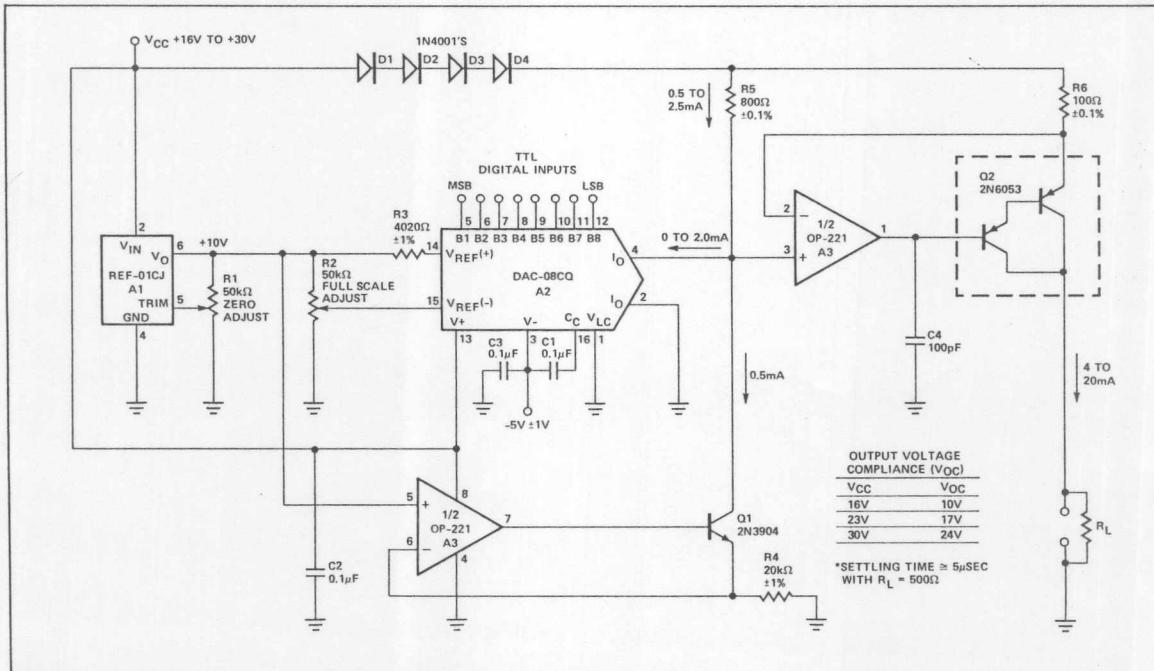
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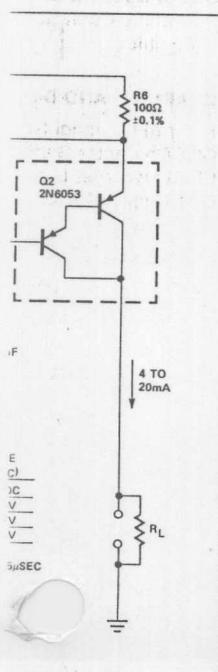
and C3 are power supply decoupling (bypass) capacitors; C4 prevents high frequency oscillations. D1 through D4 insure at least 2.5V differential between the op amp's inputs and its positive power supply under all conditions. R1 and R2 are zero scale and full scale adjustments respectively.

CALIBRATION PROCEDURE

Apply +23V ±7V and −5V ±1V to the converter with a current-measuring meter connected between the output and ground. Make the digital inputs all zeros, < +0.8V. Adjust R1 until the output current is 4.0mA. Now change the digital inputs to all ones, > +2.0V. Adjust R2 until the output current is 20mA. Calibration is now completed.

OUTPUT VOLTAGE COMPLIANCE

Output voltage compliance is V_{CC} −6V. For example, at V_{CC} = +16V, the output may go to a maximum of +10V without affecting output current. Thus, a 500Ω resistor would be the maximum load resistor at V_{CC} = +30V, V_{OC} = 24V, and R_L Maximum = 1.2kΩ.

SCALE MODIFICATION

Although the values shown are for the more common 4-20mA requirement, operation at 1-5mA or 10-50mA may be achieved by changing some components. For 10-50mA, change R6 to 40Ω; this makes the multiplying factor 20 instead of 8. For 1-5mA, replace the 2N6053 with a 2N5087, and change R6 to 400Ω.

CONCLUSION

A simple, low-cost process current converter has been shown with wide application in the controls industry. The

design is tolerant of wide power supply variations, has high voltage compliance, and is easily calibrated. Reliability and cost are optimized by using only three integrated circuits, the Precision Monolithics DAC-08, REF-01, and OP-14, plus a few readily available discrete components.

REFERENCE

Crowley, B., "Circuit Converts Voltages to 4-20mA For Industrial Control Loops," **Electronic Design**, Jan. 5, 1976, page 116.

PARTS LIST

Circuit Symbol(s)	Description
A1	+10V Reference, PMI REF-01CJ
A2	8-Bit DAC, PMI DAC-08CQ
A3	Dual Op Amp, PMI OP-221
C1-C3	0.1μF +80%/−20% 50V, Type CK-104
C4	100pF ±5% Mica, DM100ED101J03
D1-D4	Power Diode, 1N4001
Q1	NPN Transistor, 2N3904
Q2	PNP Power Darlington, Motorola 2N6053
R1-R2	50kΩ Potentiometer, Bourns #3006P-1-503
R3	4020Ω ±1%, RN55C4021F
R4	20kΩ ±1#, RN55C2002F
R5	800Ω ±0.1%, GR#8E16D800
R6	100Ω ±0.1%, GR#8E16D100

R6
100Ω
±0.1%

Q2
2N6053

...F

4 TO
20mA

E
C)
)C
V
V
V
...μSEC

R_L